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DEVELOPMENT OF AN ELECTROPHORETIC IMAGE DISPLAY

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May 1 to July 31, 1981

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Principal Investigator: Richard Liebert (914) 762-0300

Monitored by: Dr. Robert E. Kahn

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Prepared by

PHILIPS LABORATORIES
A Division of North American Philips Corporation
Briarcliff Manor, New York 10510

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(10) Richard Liebert, Joseph Lalak, Howard Sorkin, ~~R.~~ Richard Stolzenberger, ~~K.~~ Karl Wittig

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The purpose of this work is to develop an X-Y addressed electrophoretic image display. Four (4) Phase I displays with very few defects were tested with the recently completed portable driver. Two were multi-chambered to allow evaluation of different suspension formulations under identical conditions. Pigment sticking has been reduced by coating the electrodes and by adding a surfactant to the suspension. New high-purity dyes which result in better contrast are being evaluated. Antireflective coatings for reducing glare and increasing

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20. ABSTRACT (Cont'd.)

contrast are being investigated. The ion-beam milling process has been modified, eliminating the development of shorts which occurred during operation. To reduce pigment sticking, the circuitry for the Phase I driver was modified so that the voltage levels are lowered after writing. Techniques have been worked out to deposit black indium oxide onto a 12 μm layer of photopolymer and to photolithographically define the control electrode. A display using this photopolymer dielectric, rather than ion-beam-milled Mylar, is nearly complete.

PREFACE

This work is being performed by Philips Laboratories, a Division of North American Philips Corporation, Briarcliff Manor, New York under the overall supervision of Dr. Barry Singer, Director, Component and Device Research Group. Mr. Richard Liebert, Metallurgist, is the Program Leader; Mr. Joseph Lalak, Electronic Engineer, is responsible for cell fabrication and technology. Mr. Karl Wittig, Electrical Engineer, is responsible for circuit design; Dr. Howard Sorkin, Organic Chemist, is responsible for electrophoretic suspensions; Mr. Richard Stolzenberger, Physicist, is responsible for the Phase II technology.

This program is sponsored by the Defense Advanced Research Projects Agency (DARPA) and was initiated under Contract No. MDA903-79-C-0439. Dr. Robert E. Kahn is the Contracting Officer's Technical Representative for DARPA.

The work described in this eighth Quarterly Technical Report covers the period from 1 May to 31 July 1981.

SUMMARY

The purpose of this work is to develop an X-Y addressed electrophoretic image display. Four (4) Phase I displays with very few defects were tested with the recently completed portable driver. Two were multi-chambered to allow evaluation of different suspension formulations under identical conditions. Pigment sticking has been reduced by coating the electrodes and by adding a surfactant to the suspension. New high-purity dyes which result in better contrast are being evaluated. Antireflective coatings for reducing glare and increasing contrast are being investigated. The ion-beam milling process has been modified, eliminating the development of shorts which occurred during operation. To reduce pigment sticking, the circuitry for the Phase I driver was modified so that the voltage levels are lowered after writing. Techniques have been worked out to deposit black indium oxide onto a 12 μm layer of photopolymer and to photolithographically define the control electrode. A display using this photopolymer dielectric, rather than ion-beam-milled Mylar, is nearly complete.

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1. INTRODUCTION

The yield of nearly fault-free Phase I devices is improving. This is a result of elimination of opens and reduction of shorts which occur during fabrication, and reduction of shorts which develop during testing. Four improved devices were tested during this quarter. A portable driver was completed that fills all 512 character positions in the Phase I display with the 64 standard 5 x 7 ASCII characters.

Modification of the electrophoretic suspensions has resulted in reduced pigment sticking, but further work is needed to completely eliminate this problem. The Phase I driver was redesigned to reduce the likelihood of pigment sticking. Two new high-purity dyes which have improved the brightness and contrast are being evaluated.

Photopolymer technology is being developed for the Phase II display. The present method of coating the substrates has not resulted in the desired uniformity and reproducibility; therefore, commercial coating equipment is being evaluated. A method of depositing electrodes at low substrate temperatures on the photopolymer coating has been developed. A control display fabricated with Phase II technology was completed.

2. FABRICATION TECHNOLOGY

2.1 Fabrication of Row Electrodes

Glass substrates with transparent conductive layers have been obtained from an alternate vendor. However, these also have a high incidence of pin-holes, and the layers are thinner than desired. Therefore, we continue to add In_2O_3 by reactive evaporation. Nonetheless, row electrode substrates free of shorts or opens are made routinely by ion-beam milling.

2.2 Fabrication of Control Electrodes

As noted in the previous quarterly report (February-April), the rim which develops along the edge of the potential wells during ion-beam milling was believed to be contributing to electrical shorts which developed during operation. It is now believed that this rim is polymerized photoresist which cannot be removed by ultrasoneration in solvents when the lift-off-resist is removed. Unless the aluminum milling mask adheres to this rim, its presence is not expected to interfere with the device operation.

Several methods of eliminating the edge rim have been investigated. The angle between the ion-beam and the substrate was varied on the assumption that redeposit of milled material was responsible for this rim. Since this had no observable effect on the rim, another experiment was conducted to determine if redeposit was occuring. This test showed virtually no redeposit and that the material which could result from redeposit was non-conducting. In addition, it was learned that milling at angles greater than about 20° resulted in walls which sloped into the wells much more than desired. Substrates are now milled at 20° or less.

A second method for eliminating the rim is to eliminate the lift-off photoresist. Rather than using transparent In_2O_3 for the grid electrode, aluminum with an underlayer of black indium oxide was used. The black layer prevents specular reflection from the aluminum from degrading the contrast, thus the aluminum milling mask does not have to be removed and therefore the lift-off photoresist is not required. Such a substrate has been fabricated and microscopically inspected. This inspection confirms the absence of the edge rim. This substrate will be made into a cell for further evaluation.

Two methods were tried which were intended to remove dislodged portions of the rim or the entire rim, respectively. A fixture was made which would allow the application of high potential

(500 V, for instance) between a control electrode substrate and a biased electrode 0.003" away. Any material which could be dislodged during normal operation of a cell and cause shorts could be eliminated before final assembly of the cell in this fixture. Since this was found to be unnecessary if the method described below was used, pre-biasing of substrates is no longer used.

The edge rim can be removed by remilling the substrate after removal of the aluminum and lift-off photoresist. This is done at the maximum obtainable angle between the ion beam and substrate of 58°. After 3 min., the edge rim is substantially removed but milling for 6 min. is required to completely remove it. However, it has been found that the interelectrode resistance is decreased from many 10's of MΩ to only several MΩ by the 6 min. milling. The operating characteristics of completed displays indicate that the lower resistance is unacceptable, and that the small amount of edge rim remaining after 3 min. can be tolerated. Therefore, devices fabricated using the lift-off resist are now milled for only 3 min.

Resistance measurements on the substrate having the aluminum control electrode with the underlayer of black indium oxide show acceptably high values of interelectrode resistance. This is further evidence that remilling is responsible for the reduced interelectrode resistance.

2.3 Cell Fabrication

Cells fabricated during this quarter were sealed using room-temperature-curing epoxy. The only column electrode opens were found to be the result of mechanical damage during handling. The substrate having the aluminum and black indium oxide control electrode will be made into a cell using the hot-lamination method to determine if this electrode is indeed resistant to cracking during heat sealing.

2.4 Suspensions

Pigment sticking to the display electrodes results in a loss of contrast. Progress is being made toward resolving this problem. In an effort to reduce the conductivity of suspensions, the pigment is purified by extraction of soluable materials. Analysis of the material removed by this process indicates that surfactants are used in the manufacture of the pigment. Recent tests indicate that removal of these surfactants increases the tendency toward sticking. By reintroduction of surfactant into suspensions made with extracted pigment, sticking has been reduced.

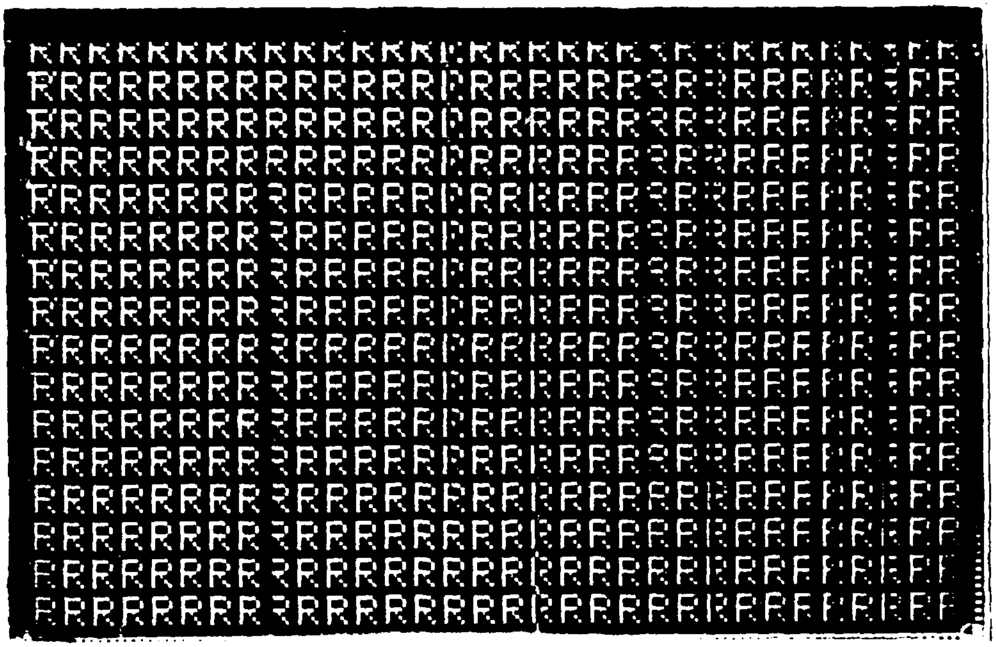
The pretreatment of cell surfaces with various organic materials prior to filling with suspensions has given mixed results. Several materials were found which looked promising initially, but continued operation eventually resulted in sticking. This indicates that these adsorbed layers lack sufficient long-term adhesion to the electrode surface.

The role of trace amounts of water in the suspension is also under investigation. To this end, a moisture analyzer was purchased and will be put into operation in the next quarter.

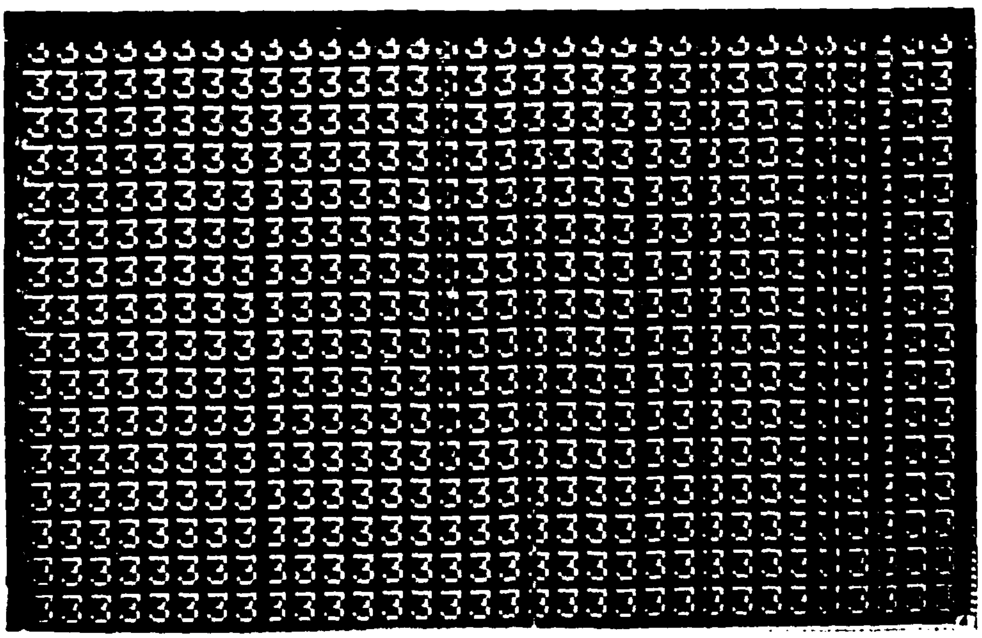
Two dyes have recently been studied. They are high purity and have high extinction coefficients. In addtion, they are only slightly adsorbed onto the surface of diarylide yellow pigment. Suspensions made with these dyes have low conductivity, and cells filled with these suspensions show improved brightness and contrast. Life test results are also promising.

3. DEVICE TESTING

Four of the Phase I devices fabricated during this quarter showed a substantial decrease in the number of shorts or opens, and none of them developed any shorts during extended periods of operation. Figures 1(a) and 1(b) are photographs of two different characters. Note that 16 lines of 32 characters are shown. Table 1 gives the driving conditions used to obtain the results of Figure 1.



(a) yellow "R" on red



(b) yellow "3" on red

Figure 1. 512 Character Phase I display showing two different characters.

TABLE 1.

	Erase	Set	Write	Hold
V_{Anode}	200 V	-100 V	200 V	30 V
V_{Row}	15 V	45 V	15 V	5 V
V_{Column}	30 V	0 V	30 V	0 V
Time	20 ms	40 ms	20 ms	Indefinite

In order to facilitate the measurment of the interelectrode resistance of completed and in-process devices, an automated measurement system is being setup to gather and record this data.

The primary failure mode of devices at this time is the build-up of pigment in the isolation lines between the row electrodes. In the present design, these isolation lines run through the potential wells. This results in a reduction in the electric field which removes the pigment from the wells. This, coupled with the tendency for pigment to stick, results in some pigment remaining in the wells and reduced contrast. New masks will be obtained which will allow fabrication of devices in which the row isolation lines do not run through the wells.

4. DRIVE ELECTRONICS

A portable driver for demonstration purposes which does not require microprocessor control has been built. The driver also incorporates a voltage reduction feature during static display of information which reduces the tendency of pigment to stick to the electrodes.

A second driver having microprocessor control which will accept data from the IEEE 488 bus is being modified to include this voltage reduction feature. The power supply circuitry for the adjustable row, column, and anode voltages was constructed, as were the supplies for the row and column driver IC's, the microprocessor and the remaining integrated circuits. The voltages are lowered either on command from the microprocessor, or when no key depression has occurred on the controlling computer keyboard for a predetermined amount of time (adjustable, about 10 seconds). Either of these conditions insures that nothing is currently being written into the display, and that only such potentials as will keep the information in the display are required.

The hardware and software modifications to implement this feature have been made in the microprocessor circuitry. Also implemented was the provision that the entire EPID display be erased (all pigment ejected from the wells) when the main power is turned off. This also serves to prevent pigment sticking when the display is not being used.

With all of the hardware constructed, the software in the development system, and a functioning display panel, integration and debugging of the entire display system is now ready to commence.

5. PHASE II

The use of a photopolymer as the dielectric support for the control electrode in the Phase II device will eliminate the necessity to ion-beam mill Mylar and thus simplify device fabrication. Photopolymer layers have been deposited on row electrode substrates with a technique which combines blade application and rotary leveling. Smooth layers have been obtained but the thickness uniformity and reproducibility are less than required. While these layers were suitable for further processing, it will be necessary to purchase a coating machine. Evaluation of such equipment is in progress.

A method for the deposition of black indium oxide onto photopolymer layers without adversely affecting their photosensitivity or surface smoothness has been developed. The black indium oxide can be photolithographically patterned and chemically etched and functions both as the grid electrode and a contact mask for the photofabrication of the potential wells in the photopolymer.

A device employing this technology was successfully fabricated. However, it failed mechanically when stresses induced by a test fixture caused the separation of the photopolymer from the substrate. It is suspected that the epoxy used to seal the cell weakened the photopolymer; therefore, other sealants are being investigated. In addition, methods of improving the adhesion of the photopolymer to the substrate, alternate device designs, and other photoreactive polymers are being considered.

In order to enhance the optical characteristics of the Phase II display, the use of antireflective coatings and a dielectric consisting of a thick transparent layer and a thin opaque layer are being investigated.

An apparatus is being designed which will introduce the suspension into the cell in an evacuated chamber. Measurements have been made using a precision digital density meter to determine the effect of temperature and time of evacuation on the specific gravity of the suspension. The rate of solvent evaporation has also been determined. These data will be used in designing the vacuum filling apparatus.

6. PLANS FOR NEXT QUARTER

a. Complete Phase I.

b. Deliver a device to ISI for evaluation.

c. Continue development of photopolymer technology for Phase II.

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